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Soil Erosion Risk Factors and the Impacts of Diversification on Organic Strawberry Farms along California's Central Coast

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An Analysis to Inform Future Research

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Photo by Kay Sterner

Introduction

Industrial, large-scale agriculture is the predominant form of food production in the United States. Based on the US government's definition of a farm, two million farms are currently operating. Only six percent of those farms produce two thirds of US output, and these high production farms have only been getting bigger over the course of the past few decades (Sumner 2014). This industrialization has been driven by increased demand, largely due to population growth, and in turn the high yield of industrial agriculture has been essential in supporting growth (Alexander et al. 2015). However industrialization is not without its costs, needing expensive inputs and creating harmful waste (Horrigan et al. 2002).

Industrial agriculture is the source of many negative environmental impacts. This includes a wide range of issues that could be (and have been) the source for whole studies, but the focus of this paper will be on soil erosion. Industrial agriculture's high yields result in much wear and tear on the land involved. Natural causes (wind and water) erode about 1% of topsoil each year, while it takes anywhere from 20 to 1,000 years to produce just one centimeter of soil (Horrigan et al. 2002). On croplands in the US, soil is lost at a rate of 17 tons per hectare every year (Pimentel et al. 1995). So while soil may technically be a renewable resource, it can take much longer to regenerate than it takes to erode, particularly under the pressure of our agricultural system. The traditional practices of tilling the soil, cultivating, harvesting and then leaving the land bare contributes to erosion when wind and water carry off the top layers of the soil (Tegtmeier& Duffy 2004). Conservation efforts have lead to a 38% decrease in cropland erosion since 1982, but agriculture is still the leading cause of soil erosion in the United States (Tegtmeier& Duffy 2004).

The main causes of erosion are the impacts of water and wind on exposed land. Wind is capable of picking up particles of soil andcarrying them long distances, while erosion is driven by water on a variety scales. Raindrops dislodge soil when they hit the ground, and bring the loose soil with them as they collect and move across the surface of the land (Pimentel 2006). Repetition of this action can cause larger-scale visible changes to the land, in the form of rills and gullies.

There are also a number of factors that interact with the effects of wind and water to alter the magnitude of erosion that occurs. One key factor is slope. When water splashes across a downhill surface, it can often take more than half of the exposed soil surface along with it. Steep lands that have been transformed from forests to farmland are especially vulnerable (Pimentel 2006).

Vegetation is another of the main aspects that influences soil erosion. When land is covered by vegetation,wind and water are dissipated by the layer of biomass(both living and dead), and roots hold the topsoil in place (Pimentel 2006). Studies have found that land with natural vegetation cover consistently experiences the lowest rates of erosion. On the other hand, land experiencing practices that inhibit vegetation growth, such as tillage and herbicide use, experience the highest rates of erosion (Lopez-Bermudez et al. 1998; Garcia-Orenes et al. 2012).

Soil erosion is important to addressbecause soil provides many ecosystem services for our society. Soil fulfills all three types of ecosystem services as classified by the Millennium Ecosystem Assessment (MEA) – provisioning, regulating and cultural services (MEA 2005; Dominati et al. 2010). In terms of provisioning services, soil provides several products that are beneficial to humans. These products include plants that provide food, wood and fiber, physical support for infrastructure, and raw material for energy and building materials. The regulating services from soil are numerous. It acts as a way of storing and processing atmospheric gases, filtering water, recycling nutrients and wastes, and mitigating floods. Research on the cultural services of soil is less robust, but there are many examples of its involvement in cultural practices. It is the medium in which many people bury their dead, and many deities have their powers based in the earth (Dominati et al. 2010). Soil is the foundation that human society is built upon – literally and figuratively.

The benefits of these ecosystem services are very difficult to quantify. However there has been some analysis of the economic benefits to soil conservation. Estimates put the cost of rigorous soil conservation (getting the U.S. to erosion rates that meet soil genesis rates) at $8.4 billion per year. These conservation efforts however would save the country $44 billion in damagescaused by soil erosion (Pimentel et al. 1995), leading to a potential net benefit of $35.6 billion for getting the U.S. to a sustainable rate of soil erosion. It is also understood that these costs of soil erosion are reflected in land prices, with land in poorer condition selling at lower prices, meaning the land market works in favor of soil conservation efforts (King and Sinden 1988).

A concept that has emerged in response to issues of agricultural sustainability, both in terms of erosion and many other problems, is diversified farming systems. A diversified farming system (DFS) is defined by Kremen et al. (2012) as a farming system that "intentionally includes functional biodiversity at multiple spatial and/or temporal scales, through practices developed via traditional and/or agroecological scientific knowledge." This functional biodiversity is beneficial to the farmer, as it makes use of natural ecosystem services (Zhang et al. 2007). Aspects of DFS can be viewed from multiple levels of the farming system, from plot scale to the surrounding landscape scale, in order to get the full picture of the potential of DFS.

On a plot scale, DFS makes use of genetic diversity within crops, and even polycultures (including tree crops). On a field scale, DFS includes polyculture, as well as noncrops (insectary strips, integration of livestock). Along the edges of fields, noncrop plantings can be used for living fences and hedgerows. On a landscape scale, DFS can interact with natural communities in the surrounding area (fallow fields, riparian zones, bodies of water, forests, etc.). These communities of plants and animals can support the systems of the farm, and in turn the DFS can support the surrounding communities (Kremen et al. 2012). These are examples and not rules, but they give an idea of the breadth and depth of the biodiversity integration behind DFS.

DFS provides a broader way of looking at sustainability in farming, taking advantage of natural systems to produce food, and thus eliminating inputs that are harmful and costly in industrial agriculture (Horrigan et al. 2002). DFS is a step up from organic farming. The whole idea behind DFS is that it does not require synthetic pesticides and fertilizers, meaning that it qualifies as organic. However, organic does not always meet the definition of DFS, often operating as industrial-scale monocultures that are far from utilizing natural ecosystem services (Kremen et al. 2012). This makes DFS a useful and necessary way of building upon the foundation of principles laid down by organic farming. This framework for farming has the potential for bringing many benefits to farmers, and the question that this paper intends to explore is – does diversification have a positive impact on soil erosion?

Study Area

The data for this research was collected from farms in Santa Cruz and Monterey County, ranging from north of Davenport to south of Salinas. A majority of the farms were concentrated in the areas of Watsonville and Prunedale (Figure 1). This can also be described as the Elkhorn Slough Watershed. The Elkhorn Slough is a salt marsh wetland – one of the last in California. The land in the watershed area is steeply sloped, with sandy loam soils, making the area particularly vulnerable to soil erosion (Rein 1999). The slough is a source of much biodiversity, supporting a wide variety of aquatic life and shorebirds, including a high percentage of threatened species (USDA 1984; Rein 1999).

Erosion presents a problem in this area for several reasons. Destruction of farm resources is a key one, such as the loss of soil and damage to crops. This results in higher costs, both from the need to fix areas impacted by erosion and in the employment of erosion prevention methods. The other key issue is where that lost soil goes. Water quality is greatly reduced when the eroded sediments reach the Elkhorn Slough. This in turn has effects on the species that call the slough home, resulting in negative consequences for both conservation efforts and recreational fishing and hunting (USDA 1984).

Figure 1. Map of the study area.

There are a wide variety of strawberry farms in this area. While all the farms in this research were organic, they ranged from large-scale monocultures to smaller, highly diversified farms. Due to the fact that many farmers are taking steps towards diversification, it is important to study how these changes are impacting their farms, in particular, the soil. It is believed that the driving tenets of diversification bring many benefits, and backing this up with data is essential. Understanding how diversification is related to erosion has the potential to bring more farmers to the practice, broadening the environmental benefits, and lessening the harmful impacts of our agricultural production.The hope is that this research can further inform the decisions strawberry farmers on the Central Coast face when it comes to implementing diversified farming systems.

Methods

In early 2016, 32 organic strawberry farms along the California Central Coast were visited and assessed for soil erosion status. Data was collected on many known factors and influences of soil erosion on farms. The variables from this data collection can be looked at in two categories – variables of visible soil erosion and variables that are understood as soil erosion risk factors. The three variables of visible soil erosion that were assessed were road gully depth, furrow erosion and sediment observed off the farm. The five variables of erosion risk factors that were assessed were hill slope of the farm, bed length, use of road plastics, furrow vegetation and road vegetation.

This data collection was an aspect of a larger study done on the diversification of organic strawberry farms along the California Central Coast, based out of University of

California Berkeley and Pomona College. The following is a more detailed description of the soil erosion variables assessed for this study:

Road Gully Depth: A continuous variable noting the average depth (in inches) of the gully erosion running alongside the road (Figure 2).

Furrow Erosion: Visible erosion occurring between the strawberry beds. A binary variable for whether erosion was observed (0) or not (1).

Off Farm Sediment: Observed run off of sediment moving beyond the farm. A binary variable for whether or not sediment was observed (0) or not (1).

Slope: The average degree of hill slope where the strawberry beds are located. A continuous variable.

Bed Length: The average length of the strawberry beds on the farm. This is a binary variable indicating beds greater than 100 meters in length (0) and less than 100 meters in length (1).

Road Plastics: The use of plastic lining alongside the edge of roads to prevent erosion. This is a binary variable indicating presence of plastic (1) or not (0) (Figure 2).

Figure 2. On the left, an example of the use of plastic alongside the road for erosion control. On the right, an example of gully erosion alongside the road.

Furrow Vegetation: The percent of furrow area covered by vegetation. A continuous variable in which 100 percent coverage is not necessarily full coverage of the ground, but simply an abundance of vegetation that would hold back erosion.

Road Vegetation: The percent of the area alongside the road that is covered by vegetation. A continuous variable in which 100 percent coverage is not necessarily full coverage of the ground, but simply an abundance of vegetation that would hold back erosion.

Summary statistics for these variables can be found in Table 1. Each of these variables were examined on a farm level, with the exception of one farm that was split into two, due to differences between two parts of the farm.

Table 1. Summary statistics for the erosion variables in this analysis.

VARIABLES	N	mean	standard deviation	min	max
Erosion Risk Factor Variables					
Slope (degrees)	33	7.697	7.720	0	30
Bed Length (m)	32	0.406	0.499	0	1
Furrow Vegetation (%)	26	0.334	0.407	0	1
Road Vegetation (%)	30	0.422	0.443	0	1
Road Plastics (0=N)	30	0.300	0.466	0	1
Visible Erosion Variables					
Furrow Erosion (0=Y)	22	0.500	0.512	0	1
Sediment off Farm (0=Y)	30	0.233	0.430	0	1
Road Gully Depth (in)	26	13.17	17.14	0	60

Regression analysis was performed for each visible erosion variable on each of the erosion risk factor variables. As both furrow erosion and sediment off farm are binary variables, they required a logistic regression, and in those scenarios odds ratios were exponentiated from the log-odds reported by the regression, for simplified interpretation of the results. For each visible erosion variable, an additional regression was performed with all erosion risk factorsincluded as controls.

These results are used to consider how well some of the conventional ideas behind soil erosion predict visible soil erosion on the farms. This information in combination with the review of erosion literature are then used to advise the creation of a plan for future data collection, which will occur in early 2017.

In addition to this analysis of erosion risk, a simple t-test was performed to get an initial idea of the relationship between diversification and erosion. Due to the broad nature of the definition of diversification, a simpler variable was used for the purposes of this study. The variable standing in for diversification in this case will be *crop style* (Table 2), described by whether or not a farm is a monoculture (single crop, given a value of 0) or a polyculture (more than 1 crop, given a value of 1). While not a full picture of diversification by any means, this variable at least gives an initial idea of how diversity on farms is related to soil erosion. A t-test of mean road gully depth by crop type was done for this analysis.

Table 2. Summary statistics for the variable crop style.

VARIABLES	N	mean	standard deviation	min	max
Crop Style (Mono=0)	26	0.500	0.510	0	1

To break this relationship down, the erosion risk factors were added to a regression of gully depth on crop style. Then, a principal components analysis (PCA) was performed on the erosion risk factor variables. This was used to further understand the relationships between the erosion risk factor variables, and the resulting components were then used to create controls for a regression of road gully depth on crop style. Only road gully depth was used as the left hand variable for this analysis. This is because it is the only continuous variable among the visible erosion variables in this data set. In addition, it is an indicator of long-term erosion, while the other variables of erosion are reset each year when the beds are made in preparation for planting of strawberries.

Hypotheses

The following is a set of hypotheses for how each erosion risk factor variable will relate to erosion based on current understanding of the influences of environmental properties and agricultural practices on soil erosion:

Slope: As slope increases, soil erosion will increase.

Bed Length: As bed length goes from <100 meters to >100 meters soil erosion will increase.

Road Plastics: As farms shift from using road plastics to no road plastics, soil erosion will increase.

Furrow Vegetation: As furrow vegetation increases, soil erosion decreases.

Road Vegetation: As road vegetation increases, soil erosion decreases.

Soil erosion will be looked at through the three visible erosion variables. Greater road gully depth values, furrow erosion = 0, and sediment off farm = 0 means more soil erosion.

For the diversification analysis, the hypothesis is that monocultures will have greater soil erosion than polycultures.

Results

Road Gully Depth

Beginning with simple regressions of road gully depth on each individual erosion risk factor variable, there are a couple of results of note. Only two of the variables can claim statistical significance in these simple regressions – bed length and road plastics. The regression on bed length shows that going from length greater than 100 meters to length less than 100 meters is linked to an average decrease of 15.33 inches in the gully depth (Table 3). With over a foot less of gully erosion, this shift is very nearly a full standard deviation of change. Road plastics have a different relationship with gully erosion. In the regression of gully depth on road plastics, going from no plastics to plastics is linked to an average increase of 16.81 inches of gully depth (Table 3). Again, this is nearly a full standard deviation of change in gully erosion.

While only two variables had statistical significance in the simple regressions, furrow vegetation had economic significance. With a small sample size, it can be difficult to find statistical significance, so it is also necessary to look at the scope of the coefficients. In the regression of gully depth on furrow vegetation, an increase in furrow vegetation from 0 to 100 percent is linked to a decrease in gully depth of 8.906 inches (Table 3).

The multivariate regression shows some changes in coefficients when controlling for other erosion risk factor variables. The road plastics variable increases slightly and retains its statistical significance, while furrow vegetation decreases slightly, remaining economically significant. On the other hand, bed length looses its statistical significance and magnitude decreases in half (Table 3).

Table 3. Regression of road gully depth on erosion risk factor variables, individually and all together.

VARIABLES	Gully Depth	Gully Depth	Gully Depth	Gully Depth	Gully Depth	Gully Depth
Slope	0.350					0.185
	(0.371)					(0.278)
Furrow Veg		-8.906				-7.551
		(7.340)				(4.576)
Road Veg			-0.234			-0.793
			(8.444)			(5.446)
Bed Length				-15.33**		-7.233
				(6.093)		(5.067)
Road Plastics					16.81**	18.87***
					(6.752)	(6.032)
Constant	9.919**	14.74***	13.28**	21***	7.353**	10.34*
	(4.116)	(4.934)	(5.527)	(5.971)	(3.443)	(5.449)
Observations	26	23	26	25	26	22
R-squared	0.026	0.055	0.000	0.204	0.226	0.631

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Furrow Erosion

In the single variable logistic regressions, we do not see much statistical significance, with the exception of road plastics. In this case, there was a decrease of 2.485 log-odds when going from no road plastics to plastics (Table 4). Exponentiating this coefficient gives you and odds ratio of 0.083. This means that going from no road plastics to road plastics, there is a 91.7 percent decrease in the odds that there is no furrow erosion. When controlling for the other soil influence variables, however, road plastic loses its statistical significance (Table 4), though the magnitude, and thus economic significance hardly changes.

While road plastics are the only statistically significant variable, there are several variables that can claim economic significance in the logistic regression of furrow erosion. Bed length has a coefficient of 0.965, providing an odds ratio of 2.625 (Table 4). This means the odds of having no furrow erosion is 162.5 percent higher on farms with beds shorter than 100 meters than those with beds longer than 100 meters. Road vegetation has a coefficient of -1.788, and thus an odds ratio of 0.167. This means that going from farms with 0 percent road vegetation to 100 percent road vegetation is linked to an 83.3 percent decrease in the odds that there will be no furrow erosion. Both of these variables see slight changes in odds ratios when controlling for the other soil influences variables, but nothing of serious magnitude.

The logistic regression of furrow erosion on furrow vegetation shows a severe change when controlling for the other variables. In the simple regression, the coefficient has hardly any magnitude, rendering it both statistically and economically insignificant. However, once all other soil influences variables are held constant, furrow vegetation stands out as the biggest influence on furrow erosion. With a coefficient of 1.372 (Table 4), the odds ratio is 3.94, meaning there is a 294% increase in the odds that there is no furrow erosion when moving from 0 furrow vegetation to 100 percent furrow vegetation.

Table 4. Logistic regression of furrow erosion on erosion risk factor variables, individually and all together. Coefficients are reported as log-odds.

VARIABLES	Furrow Erosion	Furrow Erosion	Furrow Erosion	Furrow Erosion	Furrow Erosion	Furrow Erosion
Slope	-0.125*					-0.0116
	(0.0748)					(0.0986)
Furrow Veg		0.0223				1.372
		(1.056)				(1.499)
Road Veg			-1.788			-2.345
			(1.089)			(1.859)
Bed Length				0.965		1.253
				(0.900)		(1.199)
Road Plastics					-2.485**	-2.029
					(1.211)	(1.420)
Constant	0.951	-0.00765	0.839	-0.405	0.693	0.701
	(0.685)	(0.559)	(0.681)	(0.645)	(0.548)	(1.024)
Observations	22	22	22	21	22	21

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Sediment Off Farm

Road plastics were omitted fromthe logistic regressions when sediment off farm was the dependent variable. This means that the odds ratio was 1, indicating that the odds of there being no sediment off of the farm does not change depending on whether or not there are road plastics. Though not omitted, slope also had such a small magnitude of coefficient that there was no economic significance to its odds ratio in either the single variable or the multivariate regressions.

The other three variables produced some unusual results. Both road vegetation and bed length had coefficients that were economically significant, though not as drastic in nature as some of the previous regressions on furrow erosion and gully depth. What stands out though is that both coefficients switched signs when controlling for the other predictor variables. When adding controls, the road vegetation coefficient went from 0.603 to -1.039 (Table 5). These are odds ratios of 1.83 and 0.35, respectively. Bed length did the reverse, switching from -1.05 to 0.269 (Table 5), which were odds ratios of 0.9 and 1.31. Essentially the impact of these predictor variables completely flipped when adding controls, going from having an impact on the odds of sediment off of the farm to not having an impact, and vice versa.

The final variable that stood out is furrow vegetation. In the single variable regression, the coefficient was 3.620, providing an odds ratio of 37.33. In the multivariate regression, the coefficient was 4.187, meaning an odds ratio of 65.8 (Table 5). These odds ratios stand out as much higher than the others in this analysis, implying a 6480% increase in odds of no sediment being off the farm when furrow vegetation changes from 0% to 100%.

Table 5. Logistic regression of sediment off farm on erosion risk factor variables, individually and all together. Coefficients are reported as log-odds.

VARIABLES	Sediment off farm	Sediment off farm	Sediment off farm	Sediment off farm	Sediment off farm[1]	Sediment off farm
Slope	-0.0821					-0.0577
	(0.0799)					(0.171)
Furrow Veg		3.620**				4.187*
		(1.468)				(2.147)
Road Veg			0.603			-1.039
			(1.052)			(2.202)
Bed Length				-0.105		0.269
				(0.876)		(1.316)
Constant	-0.633	-2.682***	-1.606**	-1.099*	-0.916*	-1.773
	(0.637)	(0.944)	(0.673)	(0.577)	(0.483)	(1.273)
Observations	30	25	29	29	21	17

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Diversification

A simple t-test on road gully depth indicates that there is a statistically significant difference between mean road gully depth on monoculture farms and polyculture farms (Table 6). Mean road gully depth on monocultures is 28.87 inches, while mean road gully depth on polycultures is 4.92 inches (Figure 3), a relationship that is not just statistically significant but economically significant as well.

Table 6. Basic regression of road gully depth on crop style.

VARIABLES	Gully Depth
Crop Style (Polyculture = 1)	-23.96*** (6.824)
Constant	28.87*** (5.286)
Observations	20
R-squared	0.406

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

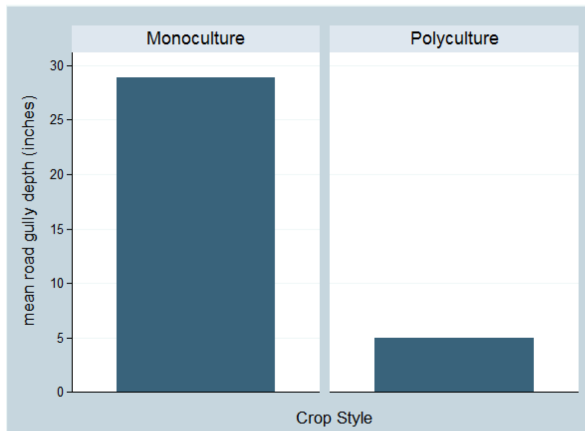

Figure 3. Bar graph of mean road gully depth on monoculture farms vs. polyculture farms.

This relationship can be broken down, using the erosion risk factor variables as controls. When adding any single erosion risk factor variable, the crop style coefficient remains statistically significant, and does not change much in magnitude (Table 7). However, when all five variables are added as controls, the coefficient looses its statistical significance, and decreases to a third of its original magnitude. When controlling for all the erosion risk factor variables, the crop style coefficient is -8.368 (Table 7). This indicates that when going from monocultures to polycultures the average road gully depth decreases by 8.368 inches.

Table 7.Regression of road gully depth on crop style, with erosion risk factor variables used as controls.

VARIABLES	Gully Depth	Gully Depth	Gully Depth	Gully Depth	Gully Depth	Gully Depth
Crop Style	-23.96***	-23.05***	-19.93**	-17.16**	-27.36***	-8.368
	(6.824)	(6.910)	(8.738)	(7.153)	(7.072)	(12.42)
Slope		0.454				0.229
		(0.478)				(0.509)
Bed Length			-6.440			-4.035
			(8.562)			(8.777)
Road Plastics				16.31*		19.53**
				(8.093)		(8.482)
Furrow Veg					-7.520	-5.177
					(7.975)	(7.267)
Road Veg					4.338	-0.835
					(8.438)	(10.27)
Constant	28.87***	24.56***	29.68***	20.72***	32.39***	15.51*
	(5.286)	(6.981)	(5.457)	(6.344)	(5.567)	(8.295)
Observations	20	20	20	20	17	17
R-squared	0.406	0.436	0.426	0.521	0.593	0.752

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The principle component analysis provided a way to consider how these controls are impacting crops style's coefficient. The PCA results were 3 components that describe 85% of the data, and these components were used to create 3 variables that could be utilized as controls – labeled as PCA 1, PCA 2, and PCA 3. Component 1 is largely described by farms with steeper slopes and more vegetation (both road and furrow). Component 2 is described by farms with longer beds, and more use of road plastics. Component 3 is largely described by farms with shorter beds and more furrow vegetation.

These components were used as controls in the regression of gully depth on crop style. This led to a loss of statistical significance and a severe decrease in magnitude for the crop style coefficient. The regression with PCA controls indicates that going from monocultures to polycultures is associated with a 6.396 inch decrease in average road gully depth (Table 8). When this relationship is further investigated by using each PCA variable individually as a control, it can be seen that PCA 2 is the component that is driving this decrease in magnitude of the crop style coefficient (Table 8).

Table 8.Regression of road gully depth on crop style with PCA components used as controls.

VARIABLES	Gully Depth	Gully Depth	Gully Depth	Gully Depth	Gully Depth
Crop Style	-23.96***	-6.396	-27.33***	-3.822	-28.28***
	(6.824)	(10.70)	(6.437)	(9.131)	(6.120)
PCA 1		0.613	0.697		
		(1.832)	(2.171)		
PCA 2		9.568**		10.29***	
		(3.883)		(3.431)	
PCA 3		1.290			3.177
		(2.478)			(2.655)
Constant	28.87***	18.63**	31.98***	17.22**	32.38***
	(5.286)	(7.232)	(5.308)	(6.383)	(5.071)
Observations	20	17	17	17	17
R-squared	0.406	0.742	0.568	0.735	0.605

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Discussion

Slope

Slope does not have a very strong showing in this analysis, and surprisingly so. It is generally understood that steep slopes are a strong indicator of soil erosion (Pimentel 2006). In all three regressions – gully depth, furrow erosion, and sediment off farm – slope claimed no statistical or economic significance. With small magnitudes and high p-values, this data and analysis would seem to say that slope does not have an impact on erosion.

Because this is contrary to common understanding of soil erosion, it is unlikely these farms are not impacted by slope. There are several possible explanations. First, despite the fact that slope was a continuous variable, this was an approximated measurement, and thus not very detailed. Most of the data collected was recorded to the nearest 5 degrees, leading to less variation than there is in reality. In addition, many of the farms did not have heavily sloped land. This can be seen from the fact that the max slope recorded was 30 degrees, while the mean slope was only 7.7 degrees (Table 1). A wider range of slopes and more accurate measurements could mean more variation and a more accurate picture of how slope affects erosion in this area. In addition, it could also be the case that farms on steep slopes are employing more methods of erosion control. In a situation of reverse causality, farmers could be more careful about erosion on steep farms because they understand the heightened risk associated with slope.

Bed Length

When looking at furrow erosion and gully depth, bed length appears to be an influential factor in these outcomes. Strong economic significance shows that short beds (<100 meters) were linked to less soil erosion – shallower gully depth and higher probability of no furrow erosion. However, bed length's relationship with sediment off farm was a little more vague. The shift in coefficient sign when adding the other variables as controls led to a confirmation of the trend that short beds are linked to less erosion, but the lack of statistical significance and much smaller odds ratio does not show a super strong relationship.

Aside from its relationship with sediment off farm, bed length shows good signs in this analysis of having a strong relationship with soil erosion. The data collected for this variable was binary. In the future, measuring this as a continuous variable could really help further analysis, and would not be a very difficult or time-consuming change to make in the data collection process.

Road Plastics

Road plastics ended up running contrary to expectations. As placing plastics alongside roads is intended to slow erosion, it is thought that plastics would mean less erosion. Road plastics were omitted from the regressions of sediment off farm, meaning the data reveals no relationship between the two variables. However, it turned up statistically significant coefficients with impressive magnitudes and odds ratios in the regressions of gully depth and furrow erosion. What was surprising was these coefficients showed that road plastics were an indication of more soil erosion.

It seems that the relationship between road plastics and erosion may be the reverse of what was hypothesized. Instead of road plastics preventing erosion and thus being an indication of less, road plastics are a response on the part of farmer to very bad erosion. This is just an idea, and would be good basis for a study on the efficacy of lining roads with plastic to prevent erosion. This study would point towards plastics not making much of an impact. Much more data collection would be necessary to fully tease apart the underlying mechanisms behind the relationship being revealed in this analysis.

Furrow Vegetation

Furrow vegetation had a very strong showing in favor of expectations. All three visible erosion variables had economically significant relationships. The regressions in this data analysis appear to support the idea that there is a link between more furrow vegetation and less soil erosion. Yet again though, the regression of sediment off farm was unusual. While it supports the hypothesis, the magnitude of the odds ratio stood out as unusually large. It was about 15 times larger than the next highest odds ratio calculated from this analysis.

There are some possibilities to explore for the reasoning behind this. Often times, unusually high odds ratios in logistic regressions are the result of multicollinearity among input variables. This could be the case, as the independent variables are all erosion risk factors, and could reasonably correlate. However this does not seem to be the cause because even in the single variable regression of sediment off farm on furrow vegetation the odds ratio is still unusually high. The likely explanation is probably just hidden in the small sample size. More data would help to uncover whether or not furrow vegetation has truly that strong of a relationship with sediment off farm, or if the result is simply a coincidence made more likely by a small sample.

Road Vegetation

The results on road vegetation were erratic. For gully depth, it had no statistical or economic significance, while for furrow erosion and sediment off farm, it ran contrary to expectations, indicating that more road vegetation leads to a greater probability that there will be erosion. Neither of these coefficients was statistically significant, but they did provide strong economic significance.

It is hard to say what may account for this result. More data is necessary to confirm that there is a causal trend happening here in contrast to common understanding that more plants and roots means less erosion. Like in the case of slope and road plastics, it could be another case of reverse causality, though if this were the case, one would expect that furrow vegetation would follow a similar pattern.

For the vegetation variables in general, there does need to be some clarification in methods of data collection. Farmersoften pull up vegetation in between beds, as they are frequently weeds, so while there may be no vegetation when the farm is visited, there could have been just days ago. In addition, season could strongly affect the growth both between furrows and alongside roads. There would also be merit to distinguishing between weeds (unwanted) vegetation and intentional planting that can occur at the ends of beds as a method of intercropping.

Sediment off Farm

With sediment off farm as the dependent variable, there was a trend of unusual results in comparison to the other two regressions. While the intention is not to toss aside unusual results just because they go against expectations, the fact that sediment off farm produced some anomalies should be explored, and there are many ways to proceed with data collection that would improve this variable for further analysis.

Making this a continuous variable would be the first change to make, though how exactly to quantify the amount of sediment running off the farm would be difficult. Instead, the best option would be to focus on securing data on the sediment ponds. This was a variable in the initial data set, but due to some messiness in the notes, it got left out for this analysis. Focusing on this would involve measuring the volume of the ponds as well as how full they are. This seems the best way to get a continuous variable for sediment runoff on the farms.

Furrow Erosion

The main adjustment that needs to be made for furrow erosion is the shift to a continuous variable. This would likely look similar to the vegetation variable, as a percentage of area experiencing erosion between the beds.

Road Gully Depth

This variable can remain as is in future data collection. It is the strongest of the visible erosion variables, thanks to the fact that it is continuous. It also stands out from the other two because it is an indication of longer-term erosion. Off farm sediment and furrow erosion are impacted by the recreation of strawberry beds each planting season, and thus indicate the yearly effects of erosion.

Some overall things to think about moving forward with this data is the lack of some very necessary controls, that would be useful to have, though are unlikely to be available due to their nature – time and weather. Due to the fact that this data collection will be a one off occurrence over only a few days, we will not be able to thoroughly control for the effects of time. Included in this consideration of time would be seasons, as well as longer-term trends over many years. There is perhaps some potential for a basic look at time as a control, as the return trip for data collection will result in data from two separate years. Weather's influence as a variable is likely to be large, due to how important water and wind are in soil erosion processes. Precipitation would be the main factor of interest, as it has a profound effect on many aspects of soil erosion (Pimentel 2006).

Diversification

The use of PCA provides a useful look at what is going on behind that initial relationship seen between diversification and erosion in the simple t-test. The results from that t-test would indicate that there is a very strong relationship between the two variables, with polycultures being linked to less erosion by an astonishing 24 inches (Table 8) in comparison to monocultures. While this is promising and a great result, a more interesting and perhaps believable situation emerged once the controls and PCA were added into the picture.

When the erosion risk factors were added to the regression of road gully depth on crop style, the coefficient for crop style decreased dramatically, to -8.368 and lost its statistical significance. When looking at regressions with each variable added individually, it became clear that no one variable is driving the change in coefficient. None of the variables alone as a control led to a big change in the crop style coefficient. Due to this collective driving of the change in significance, PCA becomes helpful to see where this change is coming from.

Using the 3 PCA components as controls in the regression of road gully depth on crop style leads to an even greater drop in the magnitude of the crop style coefficient than just using the erosion risk factor variables as controls. The fact that PCA 2 is driving this change means that there is something happening in the data where monocultures are linked with the farms described by component 2 – longer beds and more road plastic use. However, because these two variables (bed length and road plastics) do not lead to this decrease in crop style coefficient when used as a control (Table 7), there is likely a variable that PCA 2 is capturing that is not included in the erosion risk factors collected in this data set.

Yet again, road plastics are emerging as a key variable with a strong relationship to erosion. This variable is the most prominent aspect of PCA 2, the component that drives most of the crop style coefficient change. Because there is a case of reverse causality occurring with the relationship between road plastics and erosion, it is likely acting as an indicator of other erosion risk factors not considered in the data when PCA 2 is added as a control. This is again cause for further investigation into how road plastics are actually influencing soil erosion on farms.

What this analysis provides is a sort of upper and lower bounds for the relationship between crop style and road gully depth. The simple regression provides the largest possible impact, with polyculture being linked to 24 inches less of road gully erosion (Table 6), On the other hand, the PCA controls probably give the lowest possible coefficient. This is due to the fact that the PCA components are likely over controlling, so on the low end of possible relationships we have shifting from monocultures to polycultures being linked to a 6.4 inch decrease in road gully depth (Table 8). The real relationship between diversity and erosion most likely lies somewhere between these two values.

Even with this conservative look at how crop style and road gully erosion are related, this 6-inch change in erosion in not economically insignificant. With such a small sample size, it is not likely to get statistical significance, so simply looking at magnitude is necessary for the purposes of this analysis. In the end, 6 inches less of soil erosion alongside roads is an improvement. The implications of these results are great for farmers who are taking the steps to implement diversified farming systems. It is possible that beyond the environmental benefits of these changes, farmers are receiving on farm benefits as well. Soil erosion is an issue that these farms grapple with, and if diversification can help ease that problem, that helps diversified farming systems gain more traction as a method of farming that is not just essential to environmental sustainability but economic sustainability as well.

Future Data Collection

The purpose of this analysis and research is to construct a firm idea of what data needs to be collected during future research on these strawberry farms along California's Central Coast. The discussion section discussed in detail the changes that need to be made to each variable. For clarity's sake, Table 9 is a simple summary of each variable's needed alterations in the upcoming collection process. Using these changes, a data sheet was created to streamline and neaten the data collection, in the hopes that it will be clearer for future organization and analysis (Appendix 1).

As mentioned briefly before, the results from this analysis indicate that an important area for further study would be into the efficacy of road plastics as an erosion prevention method. This data indicates that the use of road plastics is linked to more soil erosion, which goes against the hypothesis that the use of road plastics leads to less soil erosion. While it may be the case that erosion would be even worse on these farms without the plastics, more research would be needed to confirm that. This would be a very useful study, as lining the side of roads with plastic is a common practice. Should it prove an ineffective means of erosion control, this would be important information for farmers looking to allocate their time and money more efficiently when it comes to curbing soil erosion.

Table 9. Summary of the changes needed for data collection on the return trip to the study area in 2017.

VARIABLE	CHANGES FOR FURTHER DATA COLLECTION
Slope	More precise measurements
Bed Length	Take measurements to make continuous
Road Plastics	None
Furrow Vegetation	Specify type of vegetation (weed vs. intercropping)
Road Vegetation	Specify type of vegetation (weed vs. intercropping)
Sediment Off Farm	Toss in favor of sediment pond to get continuous variable
Furrow Erosion	Make continuous - % of furrow space
Road Gully Depth	None
Sediment Pond - Volume	More detail and focus on this variable
Sediment Pond - % Full	More detail and focus on this variable
Weather	Add this as an aspect of the data collection process

Conclusion

Food is important. It is important due to the obvious fact that it keepsus alive, but it also is an influential aspect of cultures all around the world. This importance means we need to take seriously any threats to our agricultural system, and unfortunately that agricultural system is a threat to itself. Our food production is eroding soils at a rate that far surpasses soil genesis (Horrigan et al. 2002; Pimentel et al. 1995), and since soil is essential for food production, we have set up a system that compromises the very resource it is rooted in. This is a major problem, and it is essential that agricultural practices be reevaluated and reworked so as to avoid the collapse of our food production system and support an ever-growing human population.

This analysis stands in support with many of our ideas about soil erosion risk factors, but raises some possible questions about others. In order to continue to effectively curb erosion, prevention practices like road plastics need to be well evaluated to ensure that resources are being used efficiently in soil conservation efforts. More data collection, done more effectively with the help of this analysis, will help to create more detailed analysis of these erosion risks moving forward. This will help to build upon understanding of how erosion can be reduced.

Diversified farming systems may be a key method for reworking our agricultural systems in a way that reduces soil erosion. This analysis suggests that there are links between greater diversity of crops on farms and less erosion. This is just the beginning of an exploration of the relationship between diversification and soil erosion. What we see here are promising results that suggest diversified farming systems may be an approach to agriculture that has less of a detrimental impact on soil than industrial methods. By continuing to research the impacts of diversification on erosion, we can build a much better picture of how this concept can help our erosion depletion problem.This will provide better understanding of the potential benefits available to farmers who take the steps to diversify their farms, moving our agricultural system further down the path of environmental sustainability.

Appendix

Appendix 1: Proposed data collection sheet.

Date:			Weather Conditions:					Researcher:	
FARM	SLOPE	LENGTH	FURROW VEG	ROAD VEG	ROAD PLASTICS	GULLY DEPTH	FURROW EROSION	SEDIMENT POND volume	SEDIMENT POND % full
Notes:									
Notes:									
Notes:									
Notes:									

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